Group 12 – VLC Visible Light communication

Developing a
laser Ethernet transceiver

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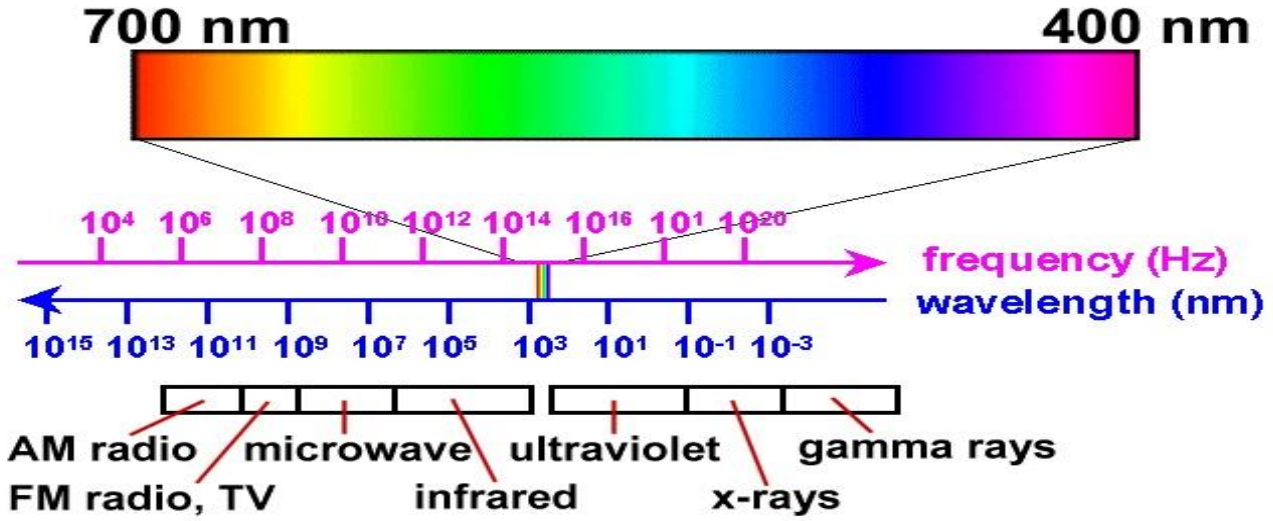
Introduction

Motivation

- Currently more than 15 billion Wi-Fi and cellular devices, estimated to be 100+ billion by 2020 causing a congested network (bandwidth is limited)
- Some areas are sensitive to electromagnetic interference
- Radio signals can easily be intercepted reducing their security
- VLC is fiber optic ready
- The visible spectrum is 100x larger than maximum radio spectrum i.e. The radio spectrum is 3 Hz - 3 THz whereas VL is 400 - 800 THz (



Introduction

Goals and Objectives

- Create a wireless Ethernet link using visible light as the carrier and free space as the medium
- Provide a system ready to be integrated into existing infrastructure
- Show that our system can wirelessly connect two routers without using radios
- Show that basic VLC systems have comparable speeds to Wi-Fi
- Keep the design small and sleek, with low power consumption and affordable price

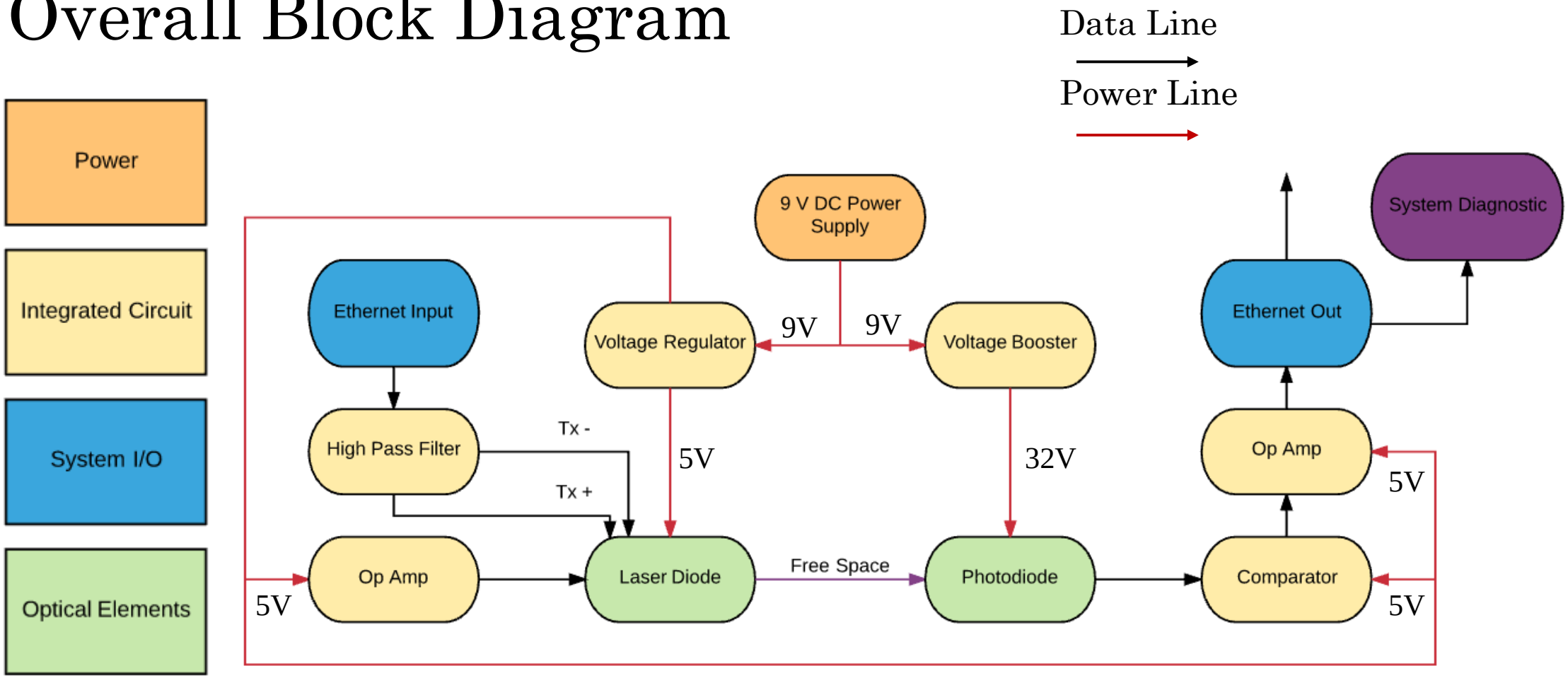
Introduction

Specification and Requirements

Component	Parameter	Design Specification
System	Usage	Full Duplex
System	Power consumption	< 15 Watts
System	Compatibility	Ethernet
Optical link	Speed	5 – 10 Mbps
Software	Diagnostic return time	< 10 seconds
Laser Diode	Output wavelength	632.5 nm
Photodiode	Spectral Sensitivity	400 nm – 1 micron

Principle of Operation

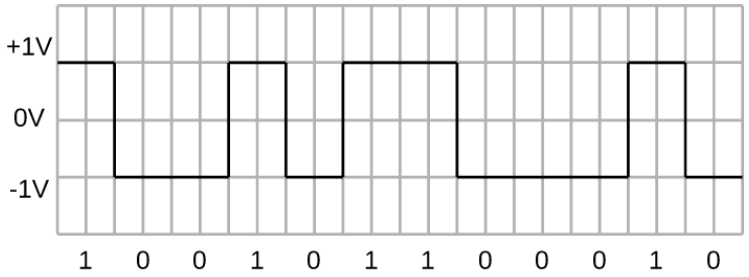
Overall Block Diagram



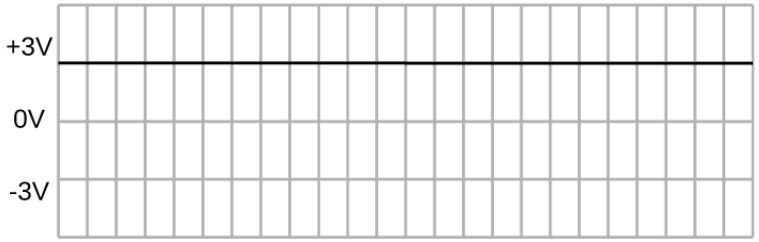
Principle of Operation

Input

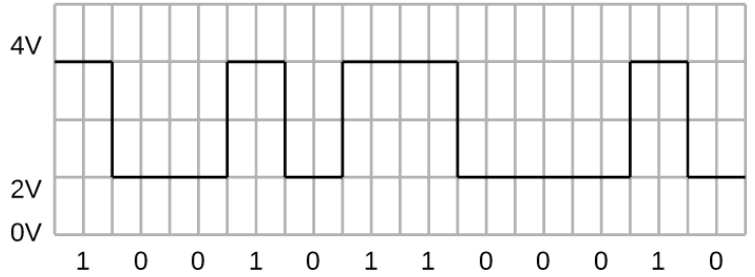
- 10Base-T signal takes values of -1 or +1
- Simplest form of OOK modulation
- Sum DC bias of laser diode, with data signal creates modulation
- When signal is -1 laser diode is dimmed
- When signal is +1 laser diode is brighter



Sample data signal +



DC bias of LD =



Signal going into LD

Principle of Operation

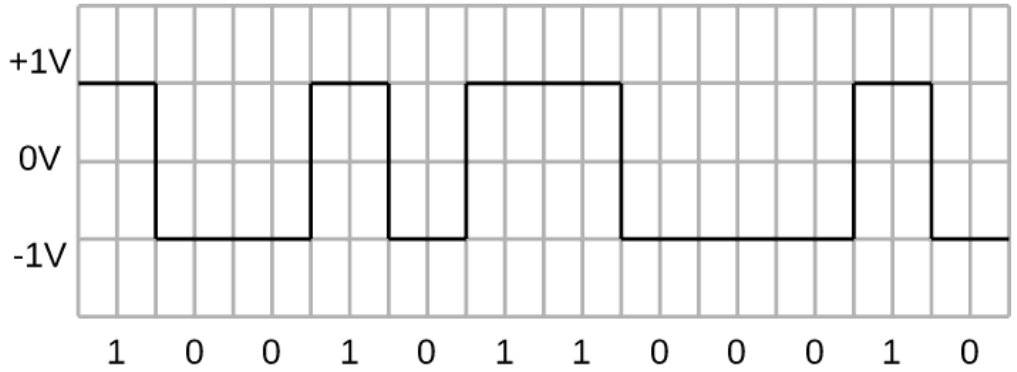
Transmission & Collection

- Signal travels through free space to be collected by the photodiode
- Photodiodes produce current relative to the incident light (intensity)
- With the use of a transimpedance amplifier we convert the current based signal into a voltage based signal

Principle of Operation

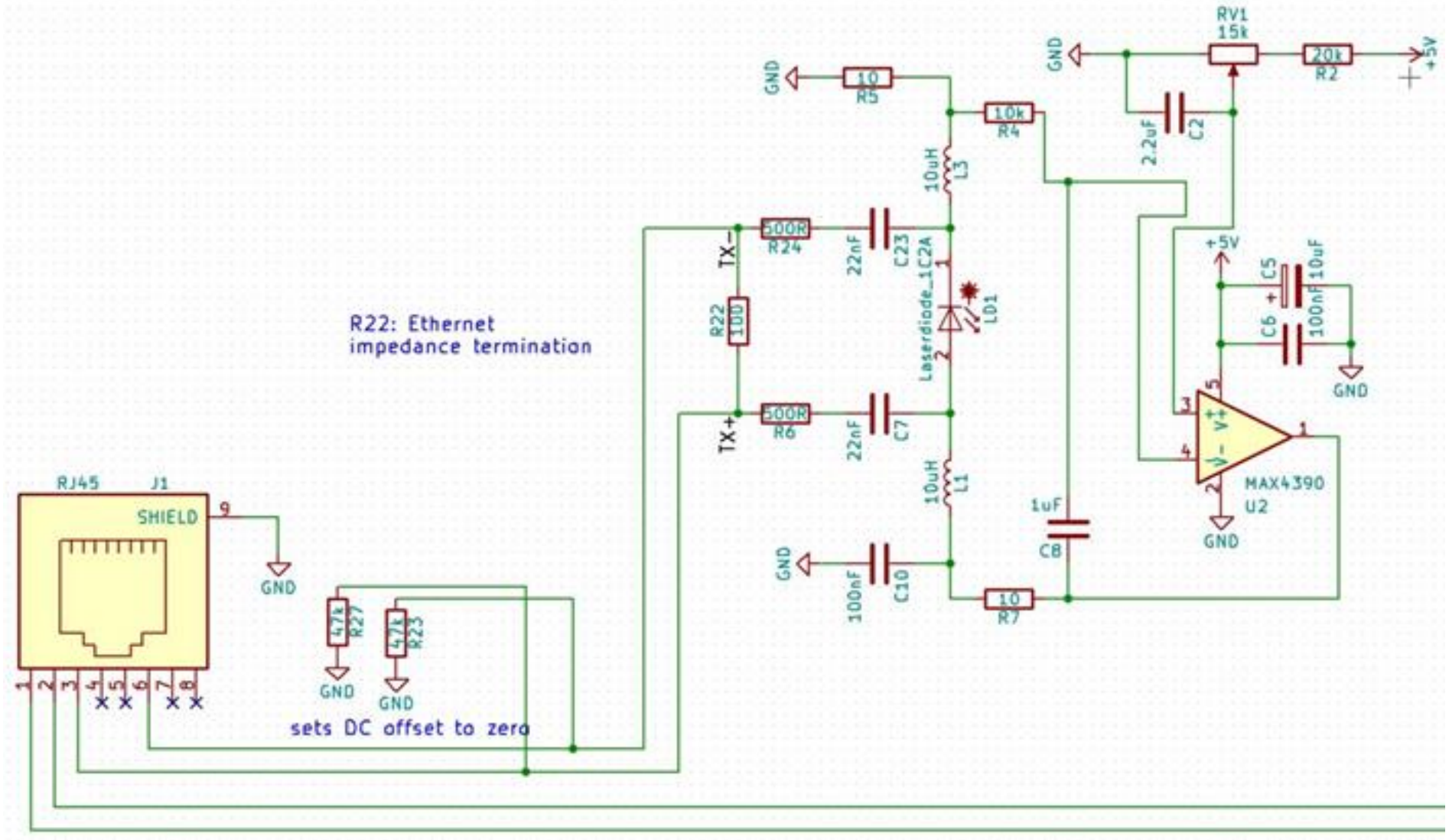
Output

- After receiving the signal from the transimpedance amp it is sent through one final op amp
- The signal is then sent to the Rx lines of the Ethernet cable in the form of a differential



Ideal signal going into the receiving end of and Ethernet cable

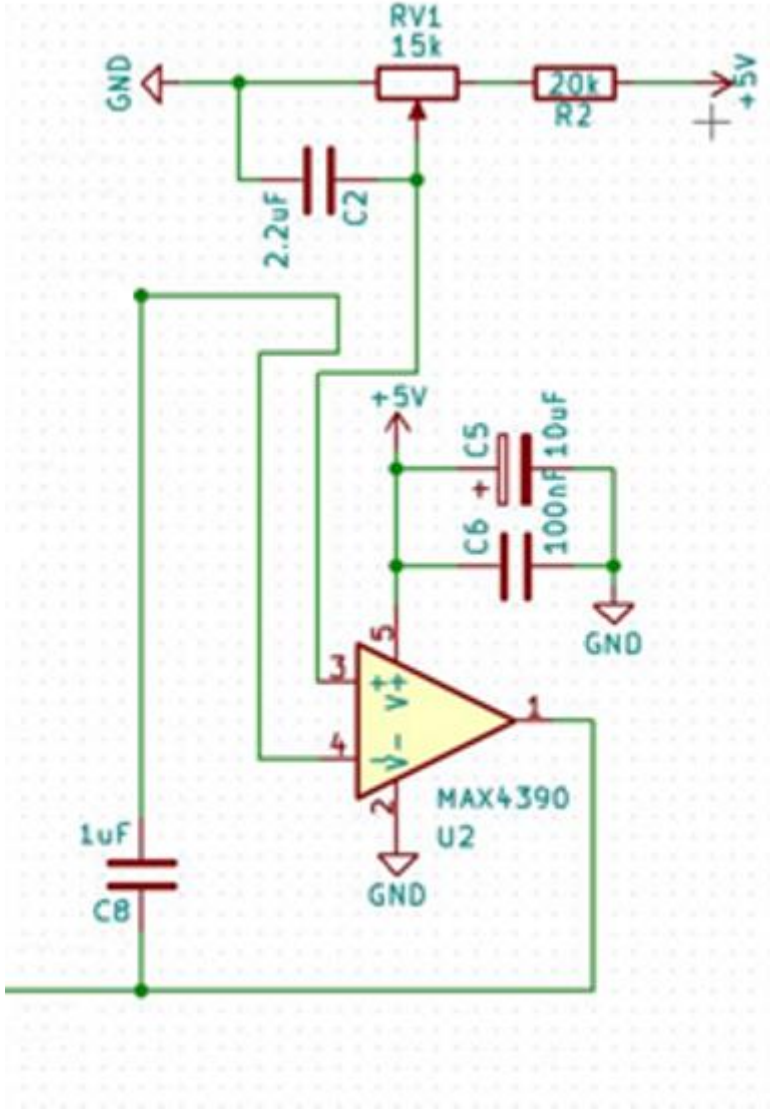
Transmitter Design



Transmitter Design

Op Amp configuration

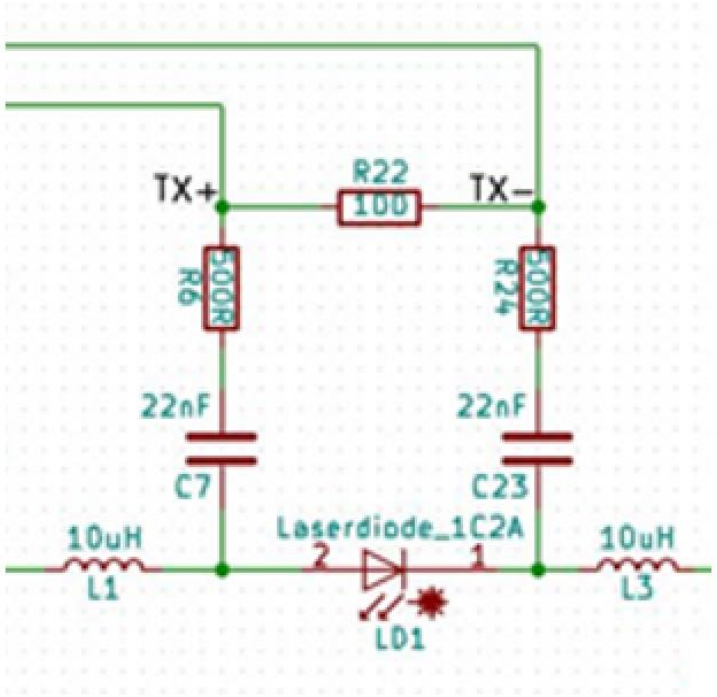
- The MAX 4390 is used as a constant current source, by making one of the resistors a potentiometer we can actively adjust the output current.
- This directly powers the laser diode with a DC signal set to about 20 mA



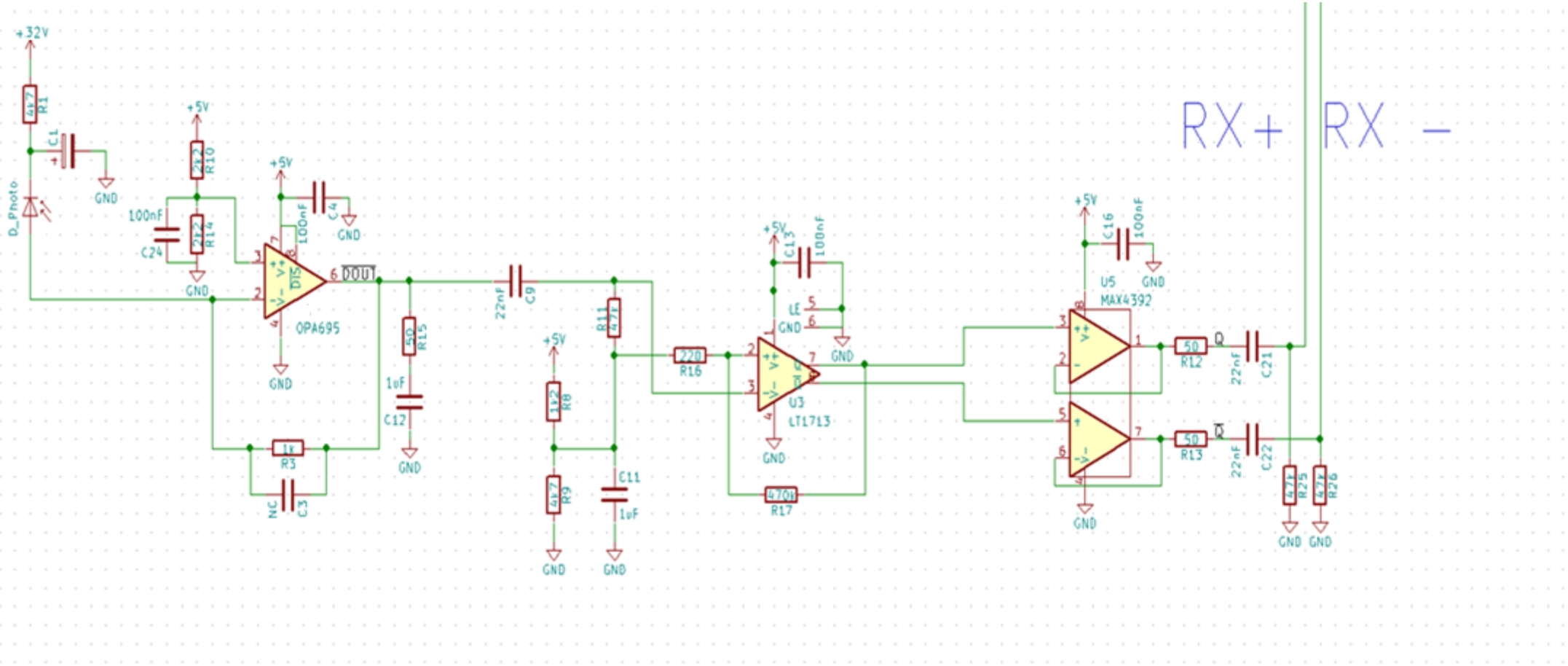
Transmitter Design

Laser Diode configuration

- The laser diode has a threshold current which creates the stimulated emission process.
- Setting the resistor value we can control the modulation amplitude while above the current threshold.
- We use capacitors to block any kind of DC signal
- We use inductors to prevent the AC signal from reaching any other part of the circuit



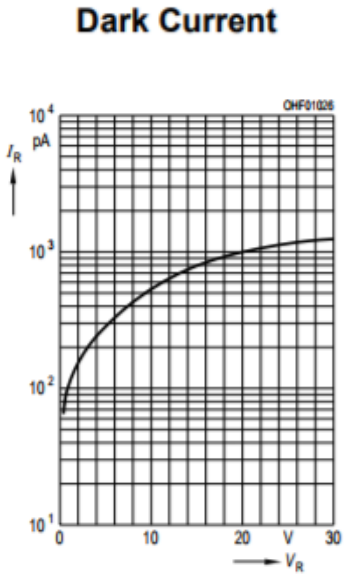
Receiver Design

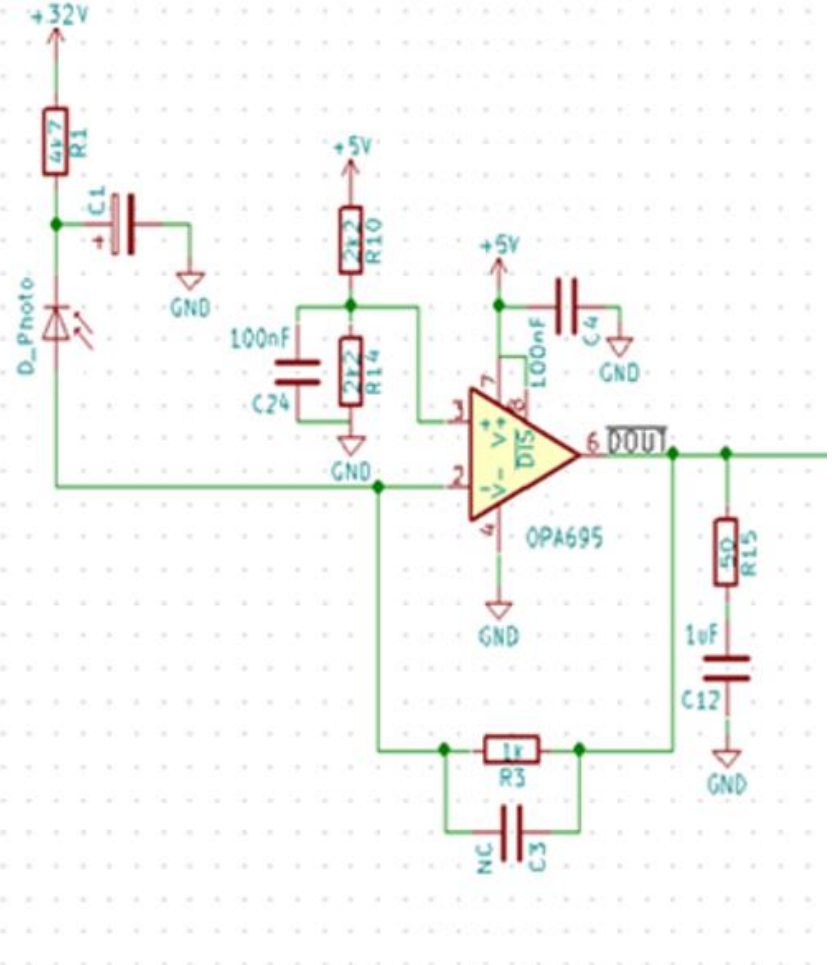


Receiver Design

Photo Diode configuration

- We reverse bias the photodiode (photoconductive mode), as we increase the bias voltage we decrease the capacitance of the diode and achieve a better response time
- The larger the reverse voltage the greater the dark current
- Passing the output of the photodiode to a transimpedance amplifier makes it ready to be processed



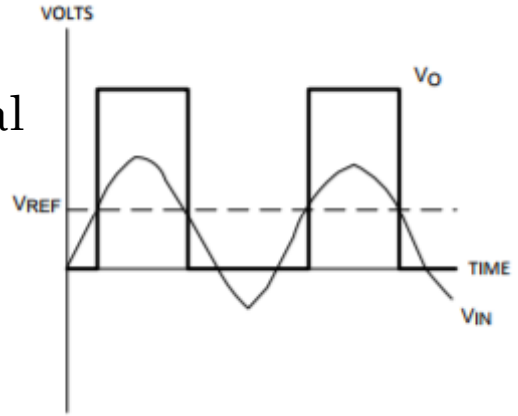


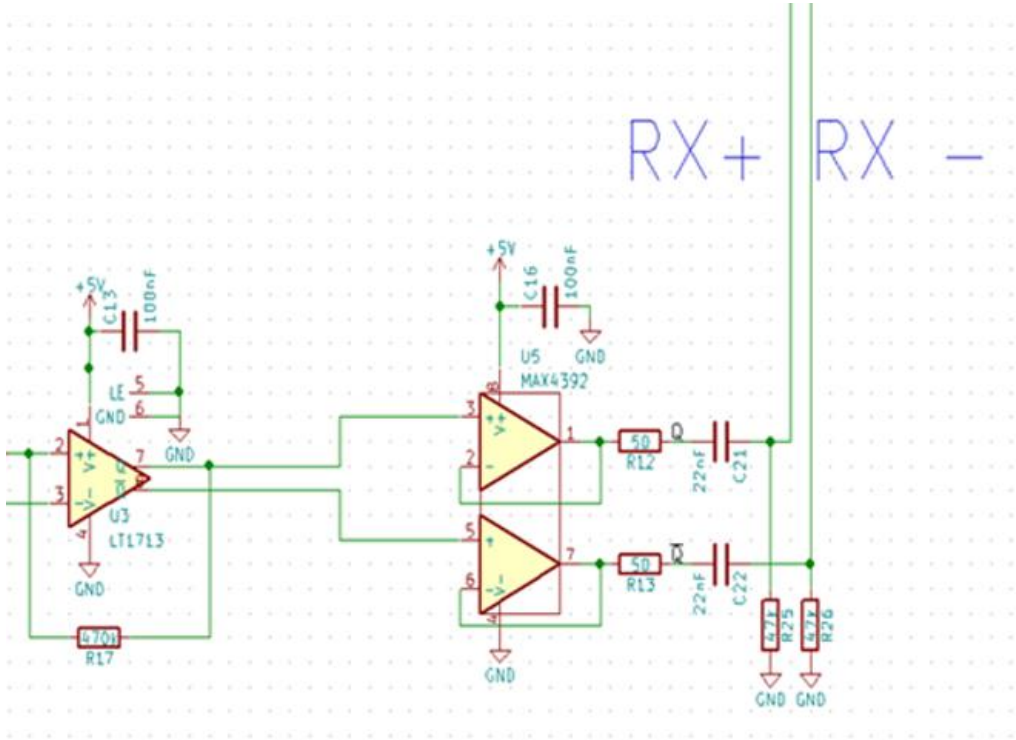
Receiver Design

Output configuration

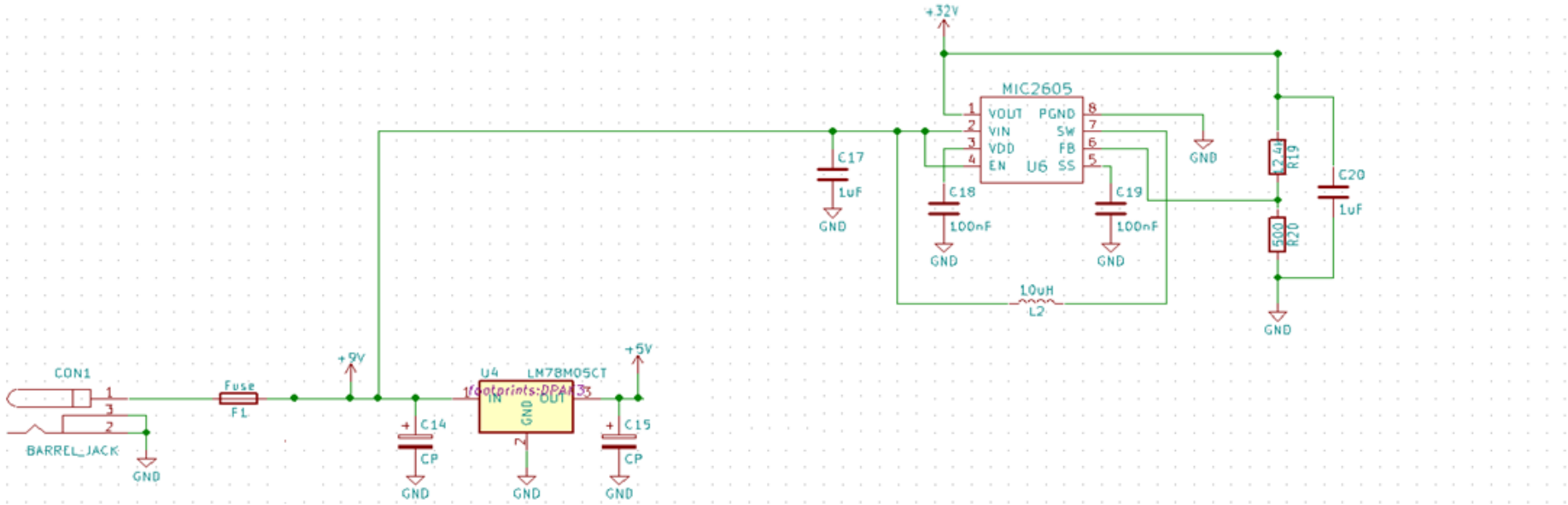
- A comparator converts the continuous signal received by the photodiode into discrete values
- The data signal is amplified one last time in order to be properly resolved by an Ethernet device

A sample signal and its output after passing a comparator





Power Supply Circuit



- The power supply consists of a barrel jack, to be connected to a wall outlet, a fuse, a voltage regulator LM78M05CT, and a voltage booster the MIC2605.

- The fuse will break if the voltage regulator is shorted, or overloaded, since this supplies the power to the rest of the components they will be protected in this instance.

Strategic Components and Part Selections

1. Operational Amplifiers - MAX4390 and MAX4392
2. Transimpedance Amplifier - OPA695
3. Comparator - LT1713
4. Voltage Converter - MIC2605
5. Voltage Regulator - LM78M05CT
6. Photodiode - SFH203
7. Laser Diode - Jameco Valuepro 154145

Operation Amplifier MAX4390 and MAX4392

- Low Cost- $1.84
- High speed- 85MHz at –3dB bandwidth
- High Output Drive 50mA
- Single 4.5V to 11V or Dual 2.25V to 5.5 V operation
- Output impedance is only 0.6 Ω which is low and easily integrate-able into a design.
- Purpose: The MAX 4390 is used to create a continuous level current bias to put the diode into lasing mode. The MAX4392 is used to amplify the signal just before going into the Rx + and Rx – lines.

Operational Amplifier-OPA695

- Cost- $5.36
- High speed- 450MHz at –3dB bandwidth
- High Output Drive 150mA
- Power supplied range 2.7V-5.5V
- Gain = +2 Bandwidth (1400 MHz)
- Ultra-High Slew Rate: 4300 V/µs
- Purpose: Placed directly after the photodiode this amp is meant to convert the current source provided by the photodiode into a voltage source, as well as aid in the overall signal resolution going into the comparator

Comparator-LT1713

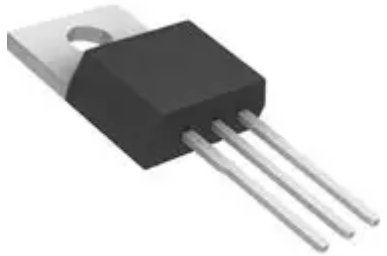
- Cost –$2.55
- Propagation delay time- 7ns
- Power Supply Range is 2.4V-12v
- Output current 20mA
- Purpose: The comparator allows for the reshaping of a the output coming out of this device which should look like a perfect square excluding the ripple effect of the Fourier components.

Voltage Booster-MIC2605

- Low Cost: $1.18
- Voltage conversion efficiency: 99%
- Power Supply Range: 4.5V-20V
- Output voltage: ≤ 40V
- Low output current
- Inverting mode: Yes
- High Speed: MIC2605 operates at 1.2MHz
- Purpose: To drive the photodiode, photodiodes in general require a bit more voltage than typical diodes, in this case about 32 V

Voltage Regulator-LM78M05CT

- Cost :$0.69
- Output current 500mA
- Output Voltage 5V and 15V
- Purpose: To provide a voltage source for the majority of the IC's on the PCB.



Photodiode- SFH203

- Cost: $0.29
- Collection range in nm: 400-1000
- Reverse voltage: 5-50V
- Dark current: ~1 nA
- Frequency Response: 270MHz
- Response time: ~5 ns
- Purpose: To collect the data signal being emitted from the laser diode

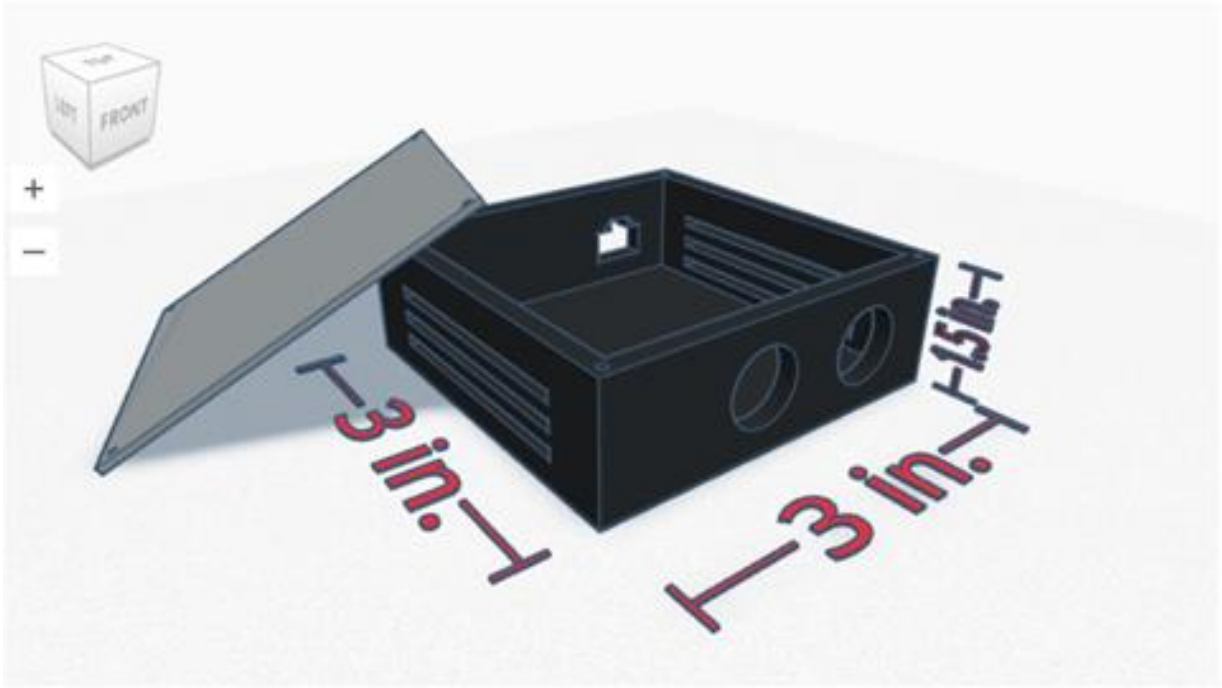
Laser-Jameco Valuepro 154145

- Cost: $3.49
- Operational Voltage: 3V
- Working current: < 40mA
- Wavelength in nm: 650
- Output power: < 5mW

- Purpose: The laser diode is the modulator for the data, its output acts as the carrier and its modulation is the data

Device Housing

- The box itself is quite small at only 3" x 3" x 1.5" in the order of length, width, then height.
- The front of the box contains two holes cut out for future lens placement
- The two sides are lined with vents to help keep the electronics cool while in operation.
- There is also a barrel jack opening for the power supply that is not shown in this rendering.
- A lid that is secured by 4 screws to keep the contents safe and locked inside.



Software

Software Requirements

- Establishing and terminating connection
- Reliable transfer of data
- Error detection
- Estimating speed of packets being transferred
- Provide a data-stream channel for large data capacity across the system
- Network statics information

Software Specifications

- This type of client/server system relies not just on the machines involved, but also in the hardware used such as PCBs (transmitter and receiver) and physical medium (Ethernet cable and Visual Light)
- The sever is synchronous, it would only accept one request and would not accept another unless the connection is terminated.
- It's highly recommend to use this application in a windows OS. There is a high possibility that it won't work properly in a different OS.

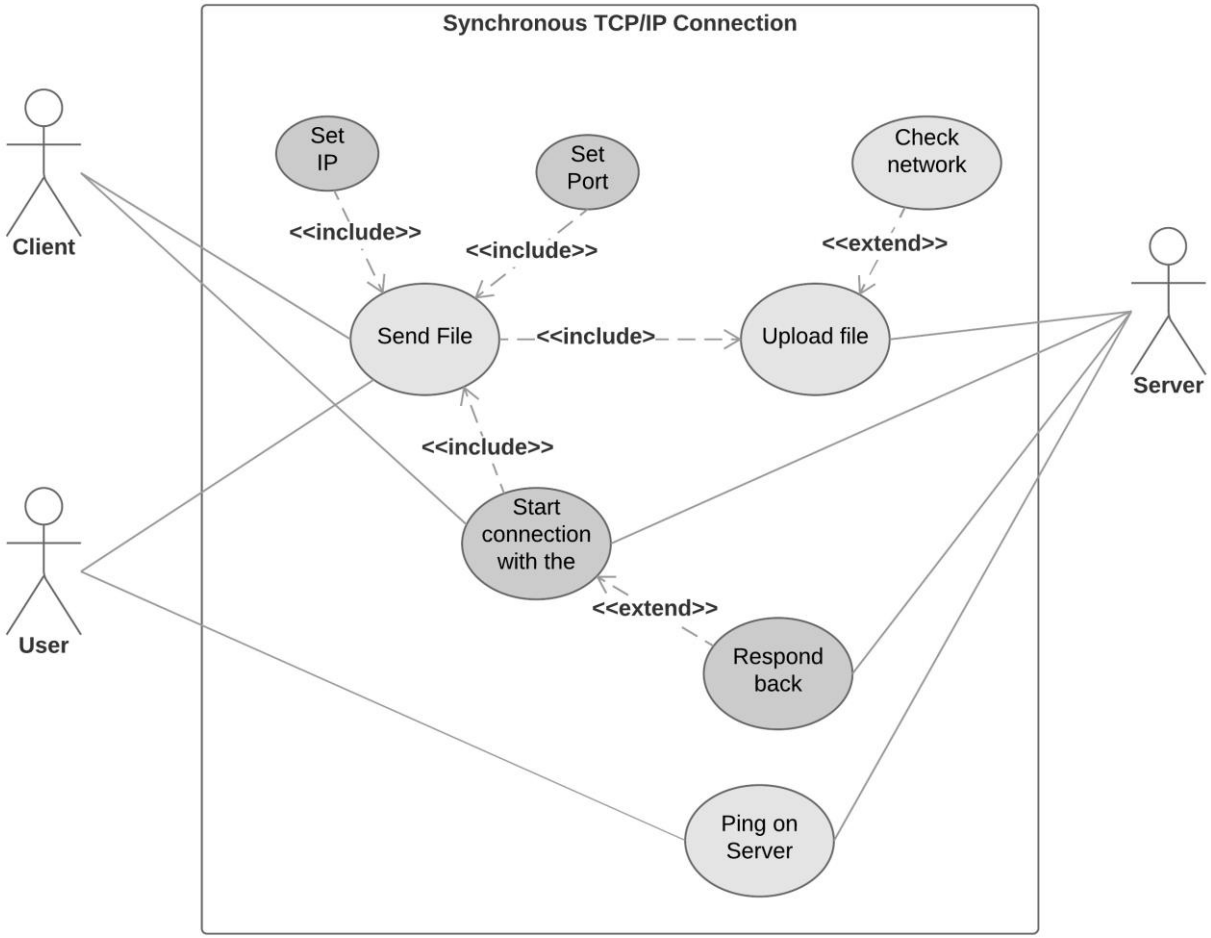
Software Development Tools

- IDE : Visual Studio
- Language: C#
- Library: .NET Framework
- Operating System: Windows (primarily) , also iOS
- Graphical Library: Windows Forms

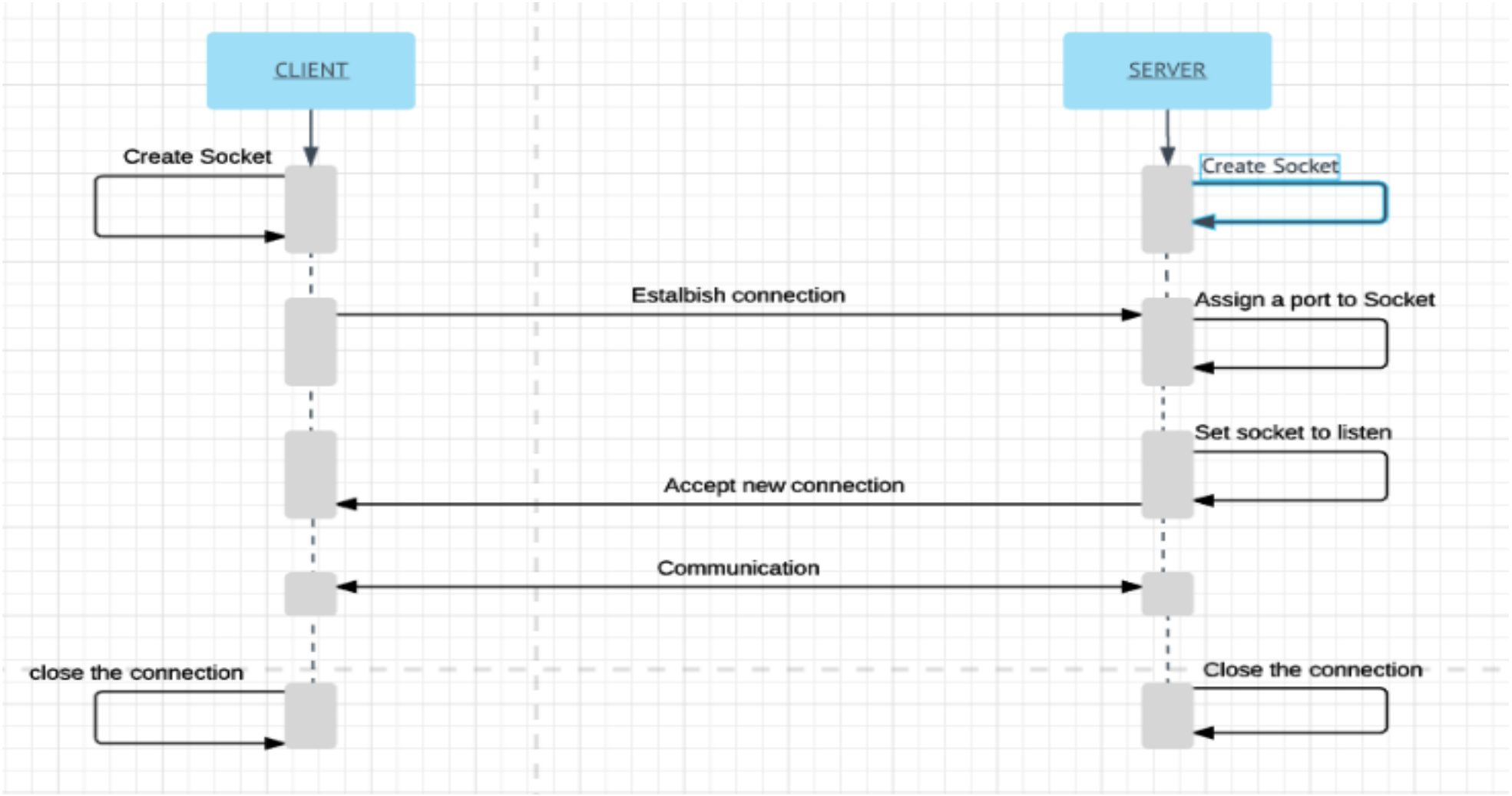
Modeling

(Use Cases)

- The application model used in this software is client/server
- Transmission system is based on TCP/IP layers
- This model specifies user views of essential behaviors from systems and actors



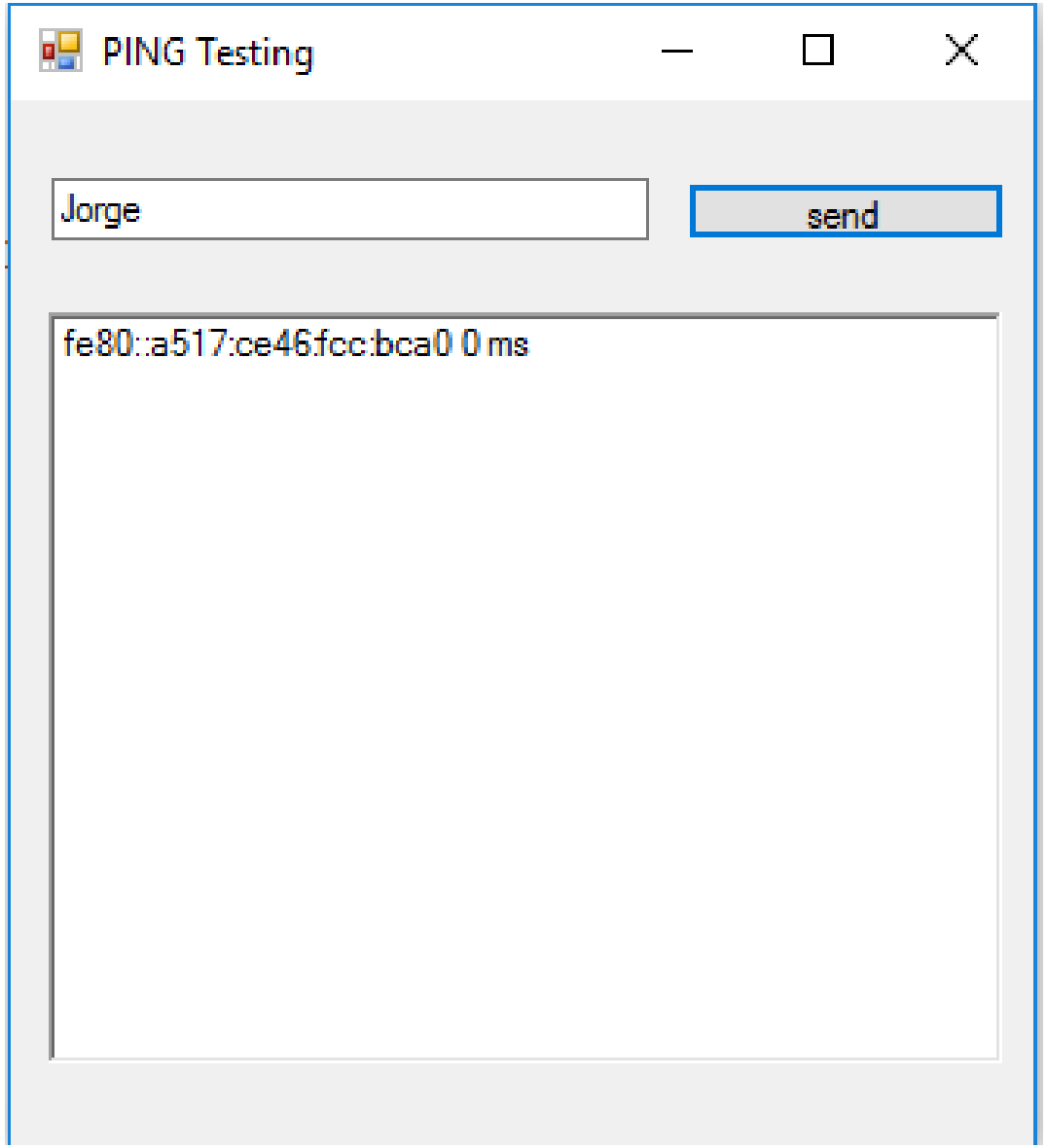
Modeling
(Message Sequence Chart)



Design

(Ping Testing)

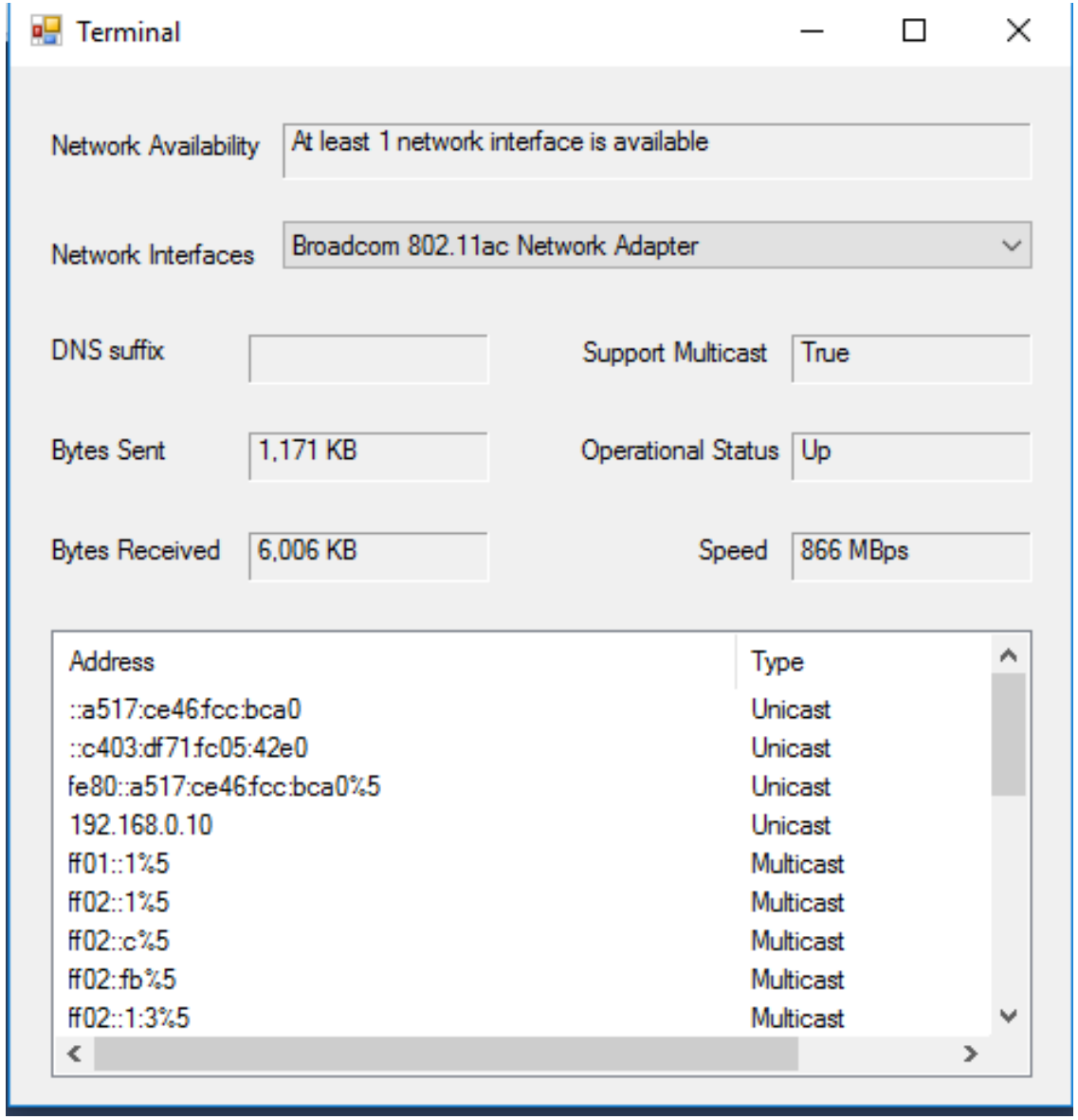
- The Ping Testing GUI is essential because it would verify if the machine we are trying to reach out to is responding
- **Functionality:**
- By writing the user's name on top blank space, we would get the IPv6 address and the time it took to reach the machine.



Design

(Network Information "Terminal")

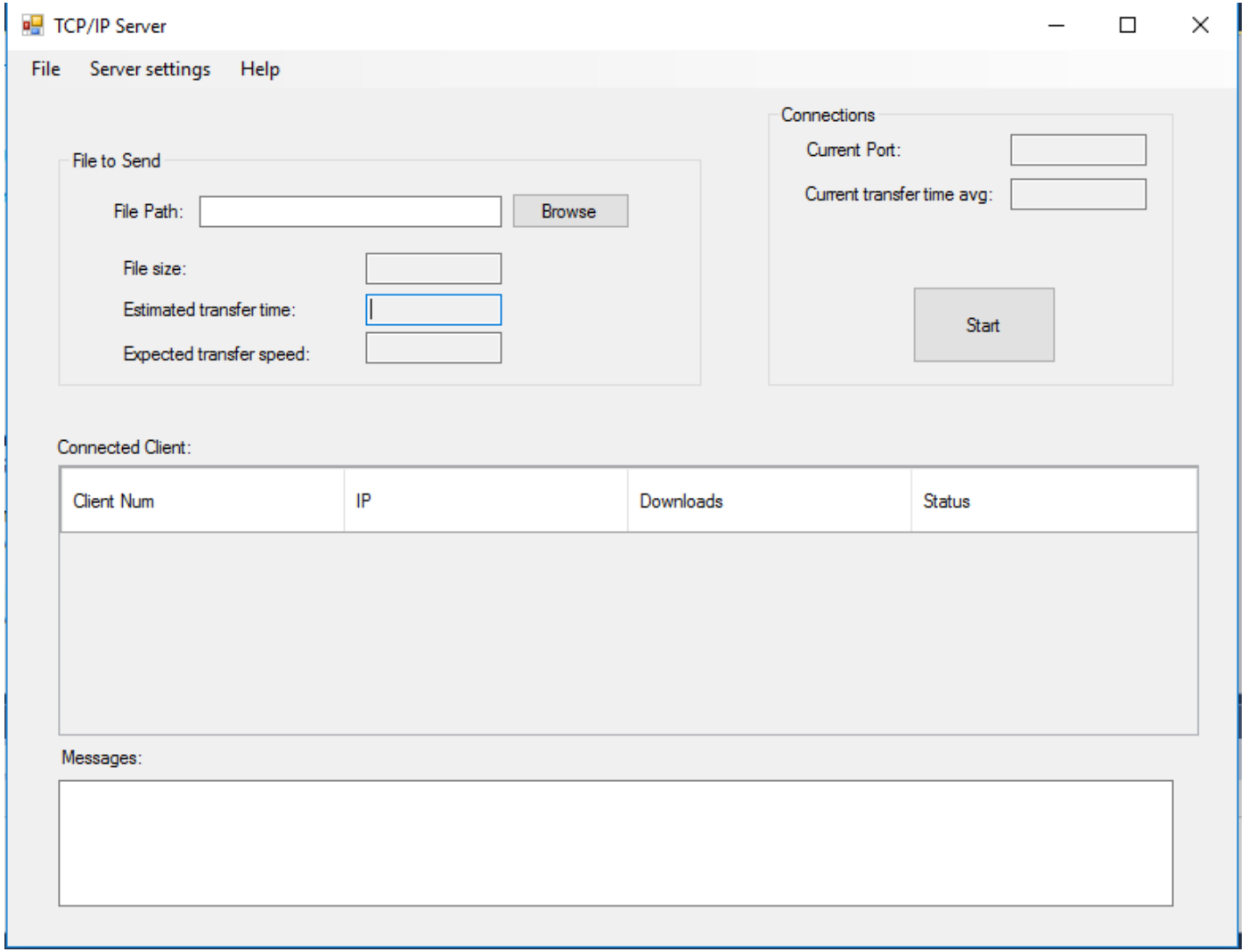
- Provides us with information of the status of whatever network interface we are running on.
- **Functionality:**
- On the 'Network Interfaces' drop-down menu, select the type of network you want to check during the transmission of data that is executed.



Design

(Server)

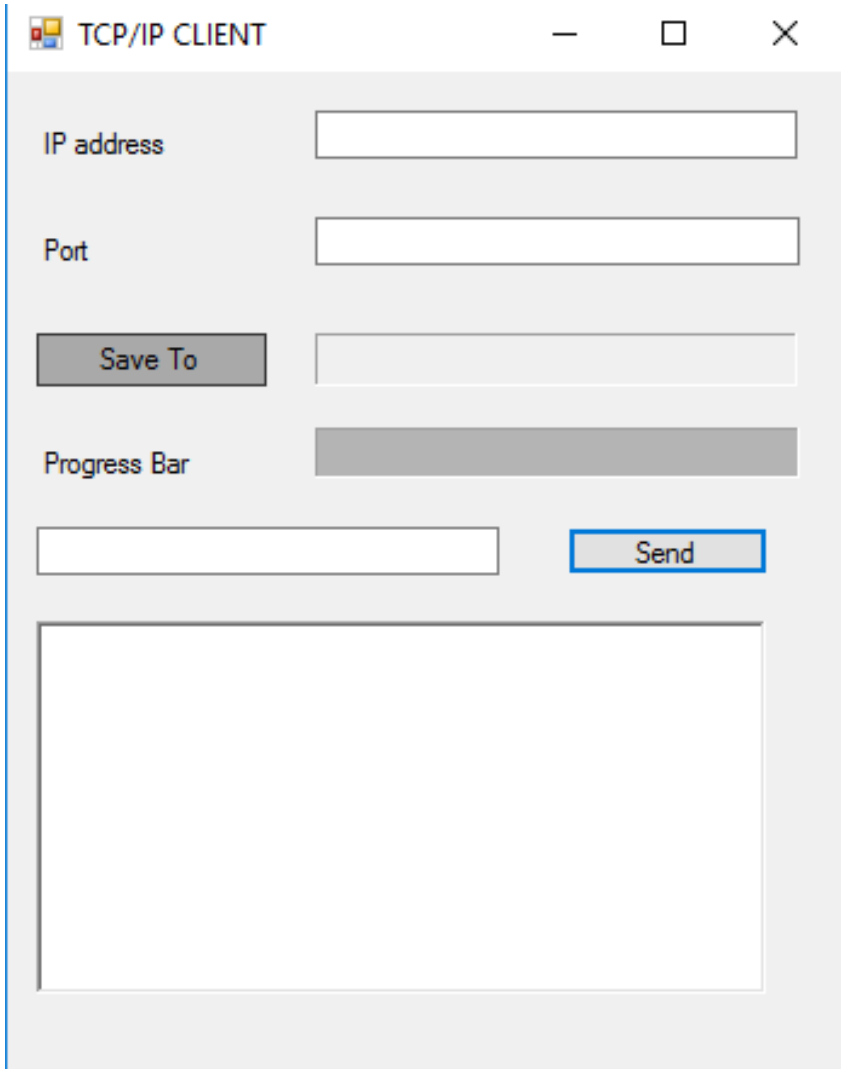
- The Sever GUI would be set up on one of the machines involved in the transmission of the data.
- This GUI will provide us with the estimated information of the link communication when data is being transferred
- **Functionality:**
- We would download the file that would be sent by selecting the 'Browse' button and then 'Start' button to make the transferring to the client



Design

(Client "Prototype")

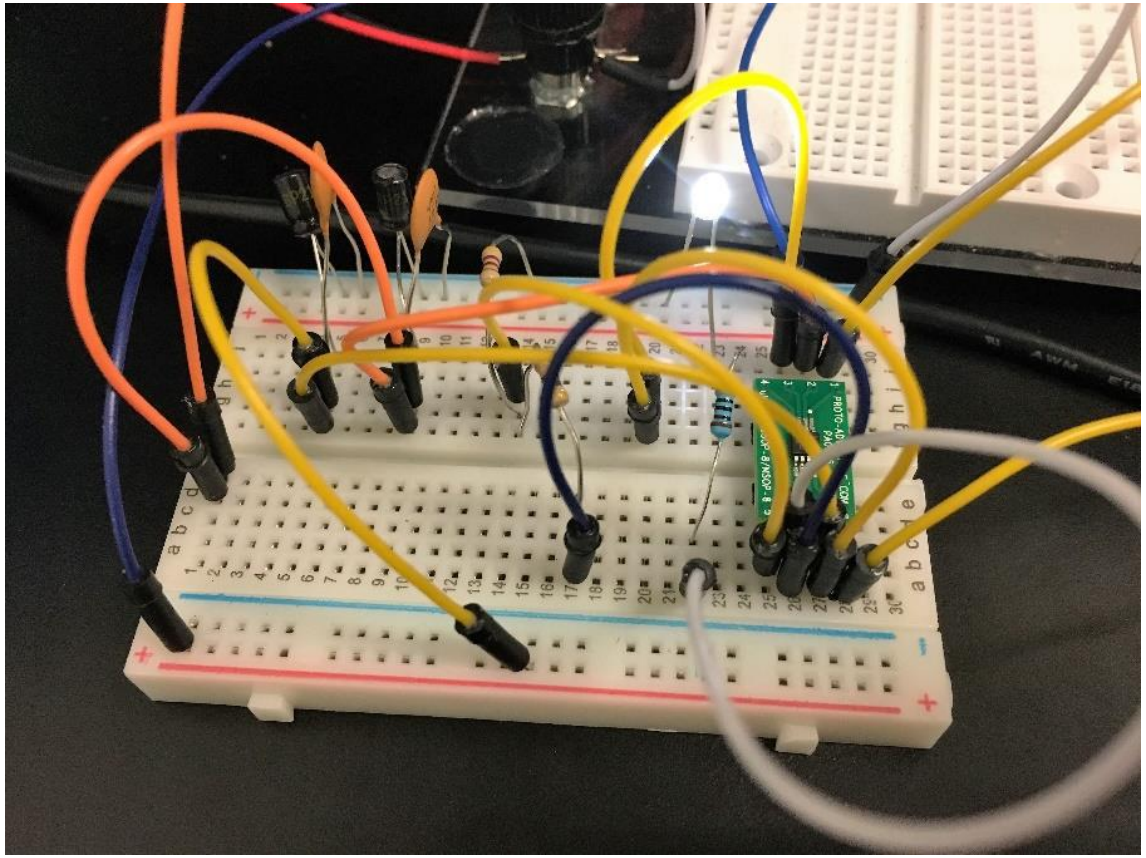
- The Client GUI would have the function of receiving the data from the server and display the information in the rich-box.
- **Functionality:**
- The data will be uploaded by the 'Save To' button.
- Write the Server's IP address and port by what the data transferring would be executed.



Software Conclusion

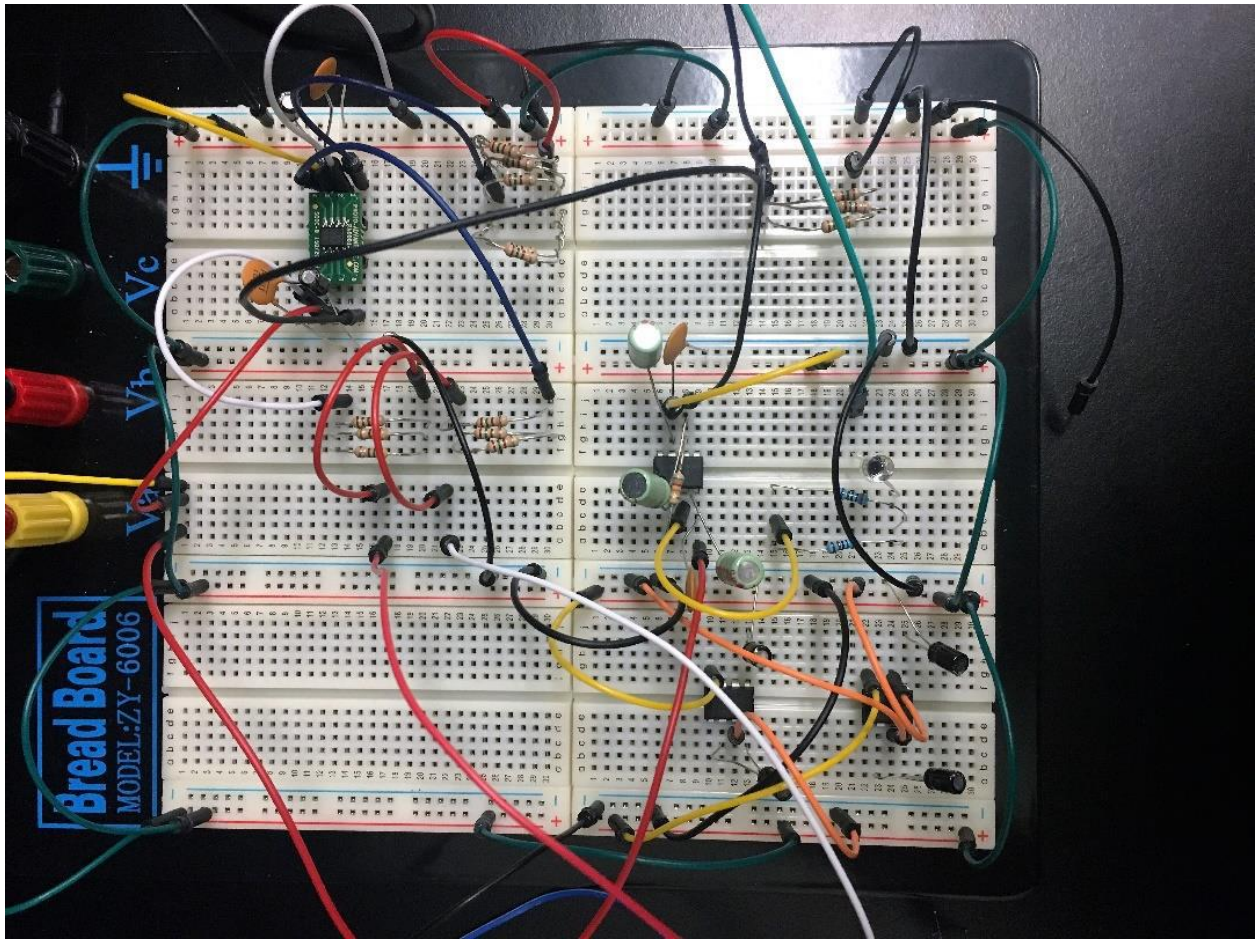
- Expectations of this software is that it will work without any problem over a new network system even where Visual Light as communication mean is NOT involved .
- The validation in this application will abide by the specifications listed earlier in the project requirements.
- Analysis of this application behaves as we expect although the client GUI is still in a prototype.

Prototyping and issues



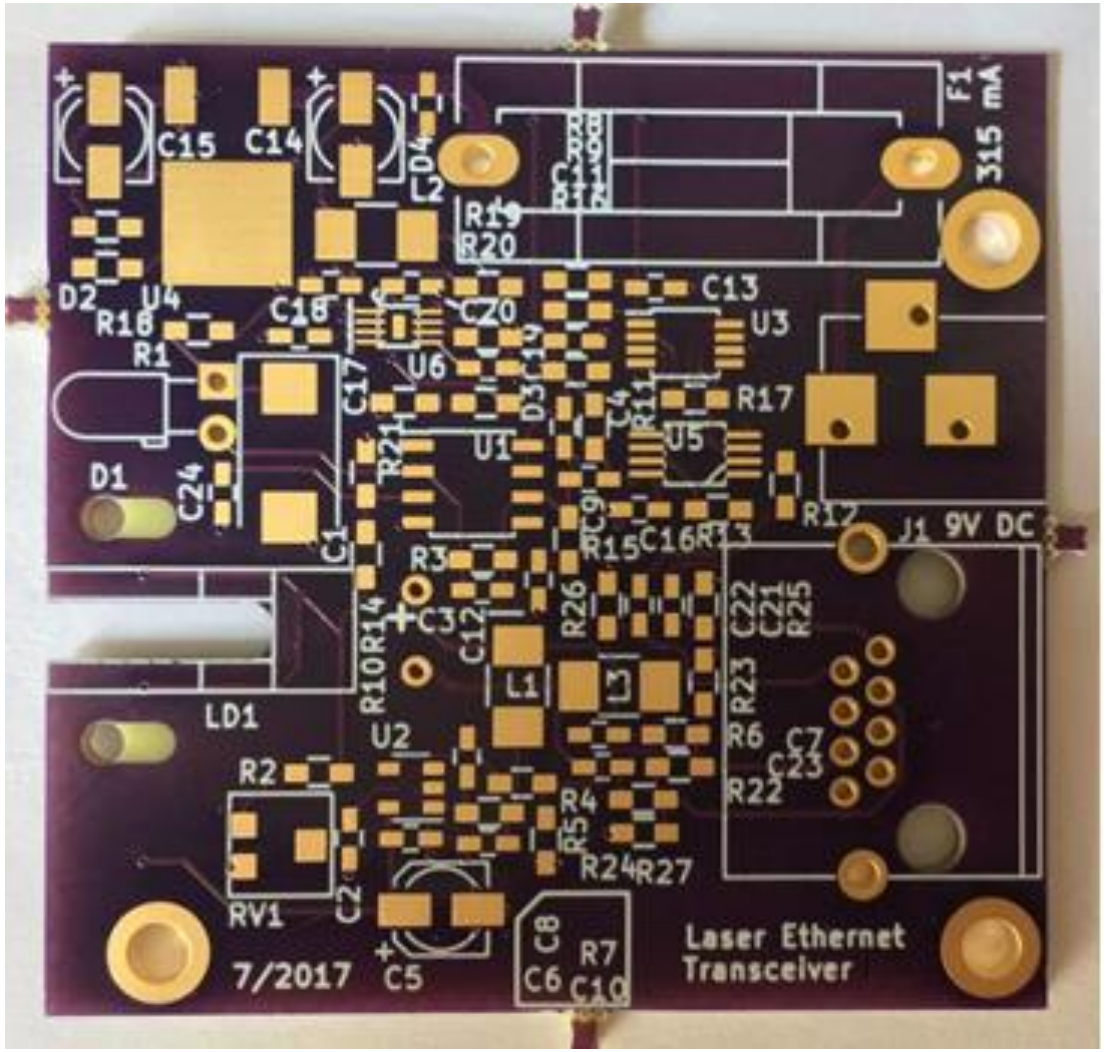
- The transmitter on the breadboard for the 10 Base-T VLC via white LED light.
- Problems include high SNR
- Range of frequency input to 10 kHz
- Testing required integration from a surface mounted IC into DIP packaging

Prototyping for receiver



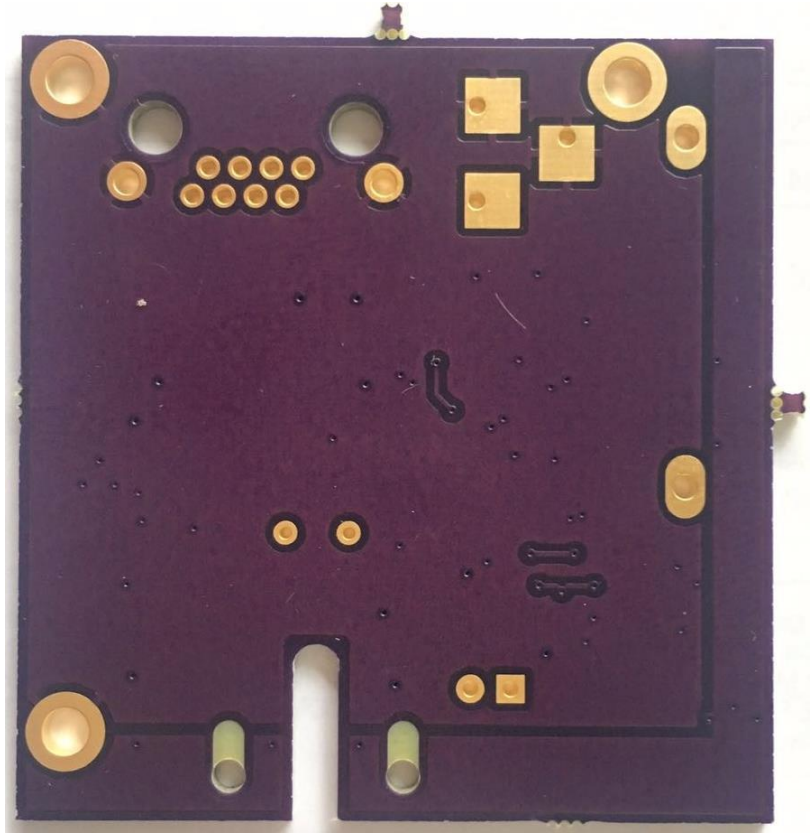
The breadboard build of the receiver.

PCB Layout



The front PCB footprint as delivered by OSH Park.
Size: 2in x 2in
All ICs will be soldering on the PCB by using surface mount technique.

PCB Layout



The back PCB footprint as delivered by OSH Park

As we can see from picture there are a few items that will be through-hole technology.

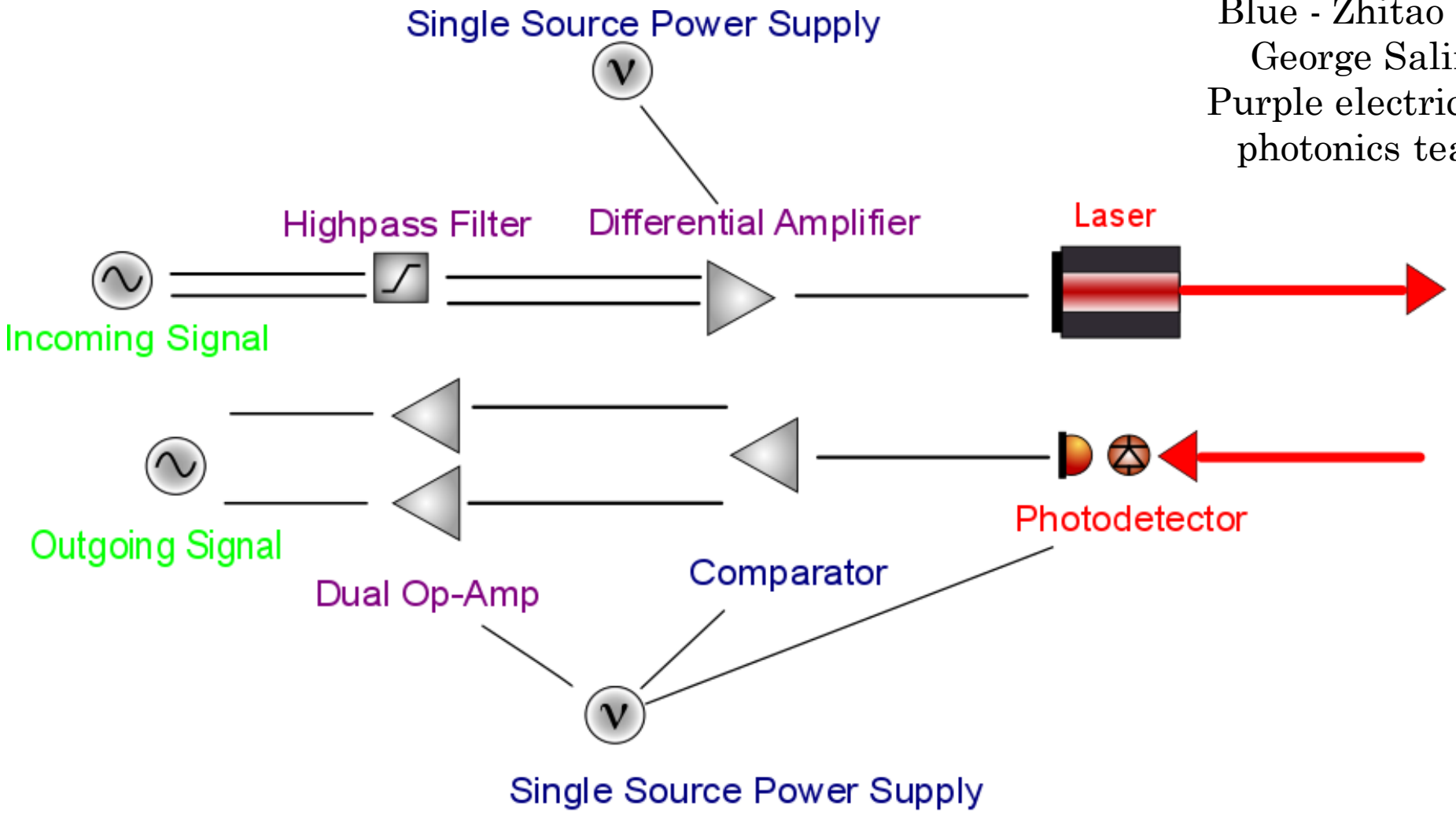
Issues

- First thoughts were to make a Li-Fi system, full duplex, and 100 Mbps speed.
- Originally we attempted to make a 100Base-T system using white light as the data carrier
- Then we attempted to make a 10Base-T version also using white light as the data carrier.
- Each proved to be extremely costly in order to be effective as well as time consuming because of the advanced digital signal processing required.
- Final solution was to make a 10Base-T system using laser diodes

Administrative Content

Work Distribution

Red - Benjamin Stuart and Garrett Bennett
Blue - Zhitao Chen, George Salinas.
Purple electrical and photonics team. t



Administrative Content

Budget

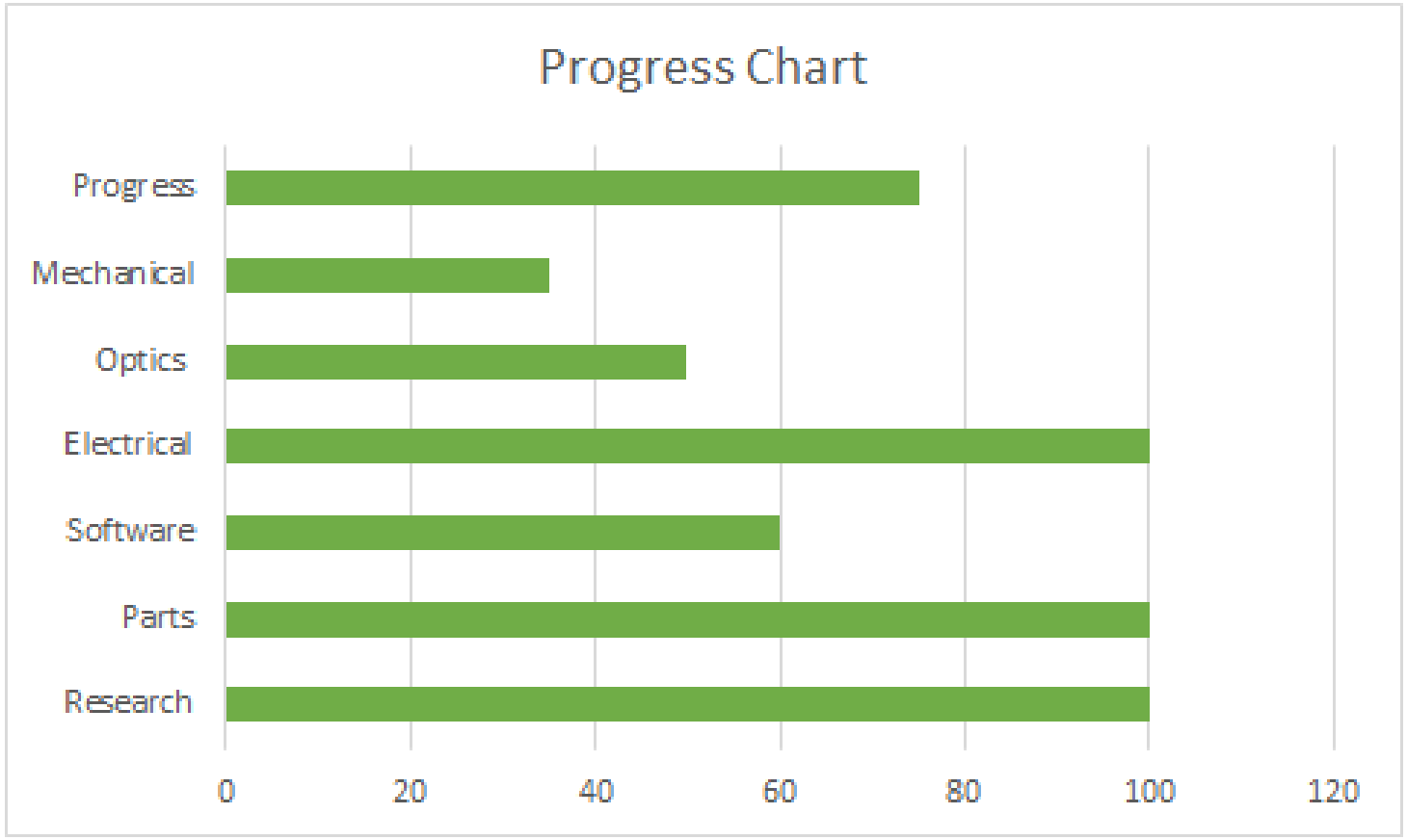
- Overall the cost of the design is $49.69 per board.
- Each component was ordered for the fact that we have six PCB's and that there would be some initial mistakes in creating such a device for the first time.
- Of course, if there was more of a reason to pursue this product professionally, there are companies which can manufacture every one of the components on to the PCB via machine vision and assembly technology such as smallbatchassembly.com.
- The 500 Ω specialty resistors cost $5.33 each.

Budgeting

Part Name	Company	Purpose	QTY	Price Each	Price Total
SMD 0603 Resitors	Various		139		$72.71
SMD Capacitors and Inductors	Various		35		$30.61
RJHSE-5380	Amphenol	RJ45 SHEILDED 8 CONT NO LEDS	6	$1.45	$8.70
MC78M05BDTRKG	ON SEMICONDUCTC	MC78M05BDTRKG	10	$0.40	$3.95
LT1713IMS8#PBF	LINEAR TECHNOLOG	LT1713IMS8#PBF	8	$4.38	$35.04
MIC2605YML-TR	MICROCHIP	MIC2605YML-TR	8	$1.13	$9.04
OPA695ID	Texas Instruments	High Speed Operational Amplifiers Ultra-Wideband Current Feedback	6	$4.37	$26.22
MAX4390EUK+T	Maxim Integrated	High Speed Operational Amplifiers 85MHz w/Rail-Rail Output	6	$1.84	$11.04
SFH 203 P	Osram Opto Semicor	Photodiodes PHOTODIODE	10	$0.66	$6.61
LT Q39E-Q1OO-25-1	Osram Opto Semicor	Standard LEDs - SMD True Green	10	$0.26	$2.64
HT-193UY-5591	Inolux	Standard LEDs - SMD Yellow 589nm 45mcd 20mA	10	$0.12	$1.18
PCB	OHS	PCB Order	6	$12.97	$77.80
Laser	Amazon	Laser Head Diode Dot Module WL Red mini 650nm 6mm 3V 5mW 10PCS	10	$0.60	$5.99
Total					**$291.53**

Administrative Content

Progress



Administrative Content

Real World Implementation

- We've essentially created a small scale model with the idea that it could be scaled using different equipment, keeping the same concept, to be used in real world applications
- A company called Koruza currently sells optical transceivers capable of 1-10Gbps speeds.

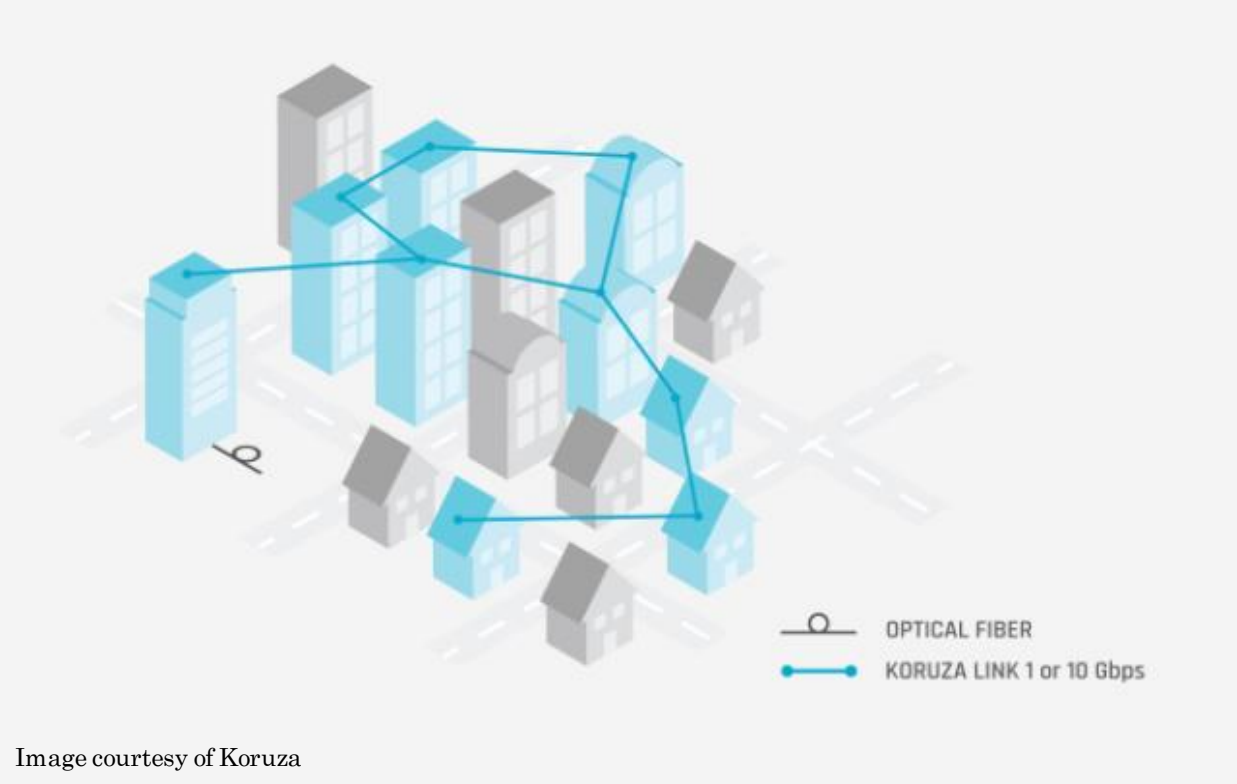


Image courtesy of Koruza

Questions?